in different phases, may lead to a fuller explanation of the "acceleration coefficients" of Harcourt and Esson. These chemists found that the change formulated

$$H_2O_2 + 2HI = 2H_2O + I_2$$

was accelerated to a definite extent by addition of sulphuric or hydrochloric acid, but that the accelerating value of each acid was different. The "acceleration coefficients," which they suggested might profitably be found for classes of salts, would measure the changes in the energies of the systems, brought about by the addition of the salts used.

The work of Prof. Gibbs will probably tend to modify the views generally held with regard to the meaning of constitutional or structural formulæ, and to lead us to regard these formulæ as crude representations of the configuration of the molecule when it has passed into the phase preceding that of absolute instability, rather than of its configuration when it is unacted on by matter in a phase different from its own, and is therefore itself in a phase of absolute stability.

Of course the possibility of predicating a general decomposition for a group of compounds, shows that these compounds all tend to pass—under the influence of one and the same reagent—into analogous unstable phases, and that their structure, before contact with the reagent, is therefore probably analogous.

Prof. Gibbs has shown how the laws of energy may be applied to the solution of chemical problems, and in doing this he has opened a new path of advance, and has supplied a guide long sought for by students of chemistry.

M. M. PATTISON MUIR

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## *A LEAF FROM THE HISTORY OF SWEDISH NATURAL SCIENCE*[1]

### I.

BEFORE the Era of Freedom (1721, 1772) Sweden had produced only four men who had earned for themselves a recognised name in the history of the natural sciences by discoveries in the field of natural research. These were Sigfrid Aron Forsius,[2] unfortunate in his predictions, author of a Mineralogy which had an extensive sale, but is full of superstition, and did not advance the science in any noteworthy degree; the quarrelsome and whimsical Upsala professor, Olof Rudbeck,[3] who, at the age of twenty-five, published his discovery of the lymphatic vessels; the physician of European reputation, Urban Hjaerne,[4] superintendent of one of the first State laboratories established for *scientific* investigation, famous for his researches regarding mineral waters, the increase of weight in metals on their oxidation, and formic acid, the discoverer of several new minerals, &c.; the afterwards so renowned mystic Emanuel Swedenborg,[5] known in the history of the natural sciences for various geological treatises of great excellence, considering the period when they were written, for a remarkable work on atomicity, for several crystallographical researches, for the largest and most complete handbook on metallurgy, &c.

These formed the whole contribution that Sweden, during her period of greatness, was able to make in this field. Here up in the remote north we had, as far as scientific research is concerned, remained completely undisturbed by the discoveries of Copernicus, Descartes, Leibnitz, and Newton, nay, even the original researches of Danish men of science such as Tycho Brahe, Steno, Bartholinus, and Roemer, had awakened no *fruitful* response on our side of the Sound.

There came, however, another period. Our short dream of greatness had come to a bloody termination. Of the Sweden formerly so powerful there remained but a maimed, depopulated nucleus, impoverished by perpetual war, whose part in the labour of the development of the race appeared to have been long ago played out. No glorious interference in the field of politics was any longer possible. But instead there began here, in the peaceful field of science, labours attended with such success that the history of other countries can scarcely show anything corresponding to it.

Our native country, where, as I have just pointed out, there was previously scarcely any scientific research, was for two decades after the peace of Nystad (1721) as fruitful in this field as any cultured state whatever, and some ten years later occupied the first rank in zoology and botany through Linnæus, in mineralogy through Wallerius and Cronstedt, in chemistry through Brandt, Cronstedt, Scheffer, Bergman, Scheele. There were also valuable contributions to the development of physics from Wassenius, Klingenstjerna, Hjorter, Celsius, Wargentin, Wilke, &c., and to the knowledge of our globe through Bergman's excellent "Description of the Globe," and the travels of the numerous pupils of Linnæus. Remarkably enough, this period of greatness in the field of research is almost conterminous in time with that "Era of Freedom" which is often depicted in so dark colours by our writers of history. It was clearly born of the spirit which accompanied the new constitution, and it got its death blow at the revolution by which Gustavus III. is said to have "saved the country."

The object of this paper is to contribute to the history of our civilisation a sketch of the influence which Swedish men of science of that age exerted on the development of chemistry and mineralogy.

The line of the great men of science from that period is headed by George Brandt, Councillor of Mines and Superintendent of the Laboratory of the Mining Board at Stockholm (born 1694, died 1768).

During the seventeenth century and the beginning of the eighteenth most of the writings of authors on chemistry still contain an unintelligible confusion of endless considerations concerning the way in which the bodies on the earth's surface are composed of certain supposed primitive substances, for instance, according to the school of Aristotle, of fire, earth, water, and air; according to Basil Valentine and Paracelsus, of certain elementary principles—salt, sulphur, and quicksilver. The service of having shown the groundlessness of these fancies is to be ascribed to the great English *savant*, Robert Boyle (died 1691). In opposition to his predecessors, he laid down the fundamental principle that the chemist ought to consider every body as simple which with the means at his disposal he cannot chemically decompose, a principle which indeed took from chemistry much of the glitter of learning with which it before was bedecked, and which in the eyes of philosophers reduced this science to an art of cookery, which in any case, when the old creations of fancy, constructed with so much trouble and subtlety, were blown away, gave the science a stable foundation to build on. Boyle's fundamental principle has since been further developed, and now forms one of the corner-stones of the modern chemistry—although it must be admitted that it is little in accordance with the simplicity which otherwise prevails in nature, that the material world should consist of more than sixty different elements. Certain it is in any case that the elements in question, at least for the present, cannot be decomposed or transmuted into one another either by the most powerful decomposing agents, by the vital forces of plants, or by fire, or by electricity. They thus form the raw material of which everything in nature, whether living or inanimate, is composed. In such circumstances it is clear that an accurate knowledge of these elements forms the first condition for the development of chemistry, and that the discovery of a new element must often be of such importance as to form an epoch in the history of the science.

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[1] Translated from a paper by Prof. A. E. Nordenskjöld, of Stockholm.

[2] Born at Helsingfors after the middle of the sixteenth century; died 1637.

[3] Born 1630, died 1702. His discovery of the lymphatic vessels was published in 1653.

[4] Born 1641; died at Stockholm in 1724.

[5] Swedenborg was born in 1688; died in 1772. The greater portion of his period of activity therefore falls under the Era of Freedom, but most of his scientific works were published before 1721, among them his "Prodromus Principiorum Rerum Naturalium," in which, among other things, he attempts to explain the physical properties of bodies, on the supposition that they are composed of an endless number of minute atoms. His great metallurgic works were first published in 1734. In the *Transactions* of the Royal Academy of Sciences he published, as late as 1763, a "Description of a Method of Inlaying Tables and other Furniture with Marble," free from all mysticism. The table described in this paper is still preserved at the office of the Swedish Board of Trade.

This was especially the case at first, when many of the elements that occur most generally in nature, and there play a very important part, were yet unknown, and when nearly every new discovery in that field presupposed a new method of research which could also be employed in other directions. Many questions, too, which now appear self-evident were formerly very difficult of investigation on account of the faulty methods of research which were then generally employed. The history of chemistry during the last century shows that the Swedish school of chemistry was the first that taught the chemist to question nature in the right way, and to arrange his experiments so that to a *proper* question he got a *proper* answer. Urban Hjaerne may be considered as the founder of this school, Brandt as the eldest of his pupils who took part in the development of the science.

The first chemical work by which Brandt gained for himself an honoured name in the history of chemistry was his researches "De Arsenico," and "De semi-metallis," published in *Acta litteraria et scientiarum Sueciæ* (Upsala, 1733 and 1735), in which he showed, among other things, that arsenic, with reference to which the views generally entertained were uncertain and hesitating, must, on account of its physical and chemical properties, be considered a (semi) metal, whose "kalk" is the white arsenic (arsenious acid). Of great importance for the mineral chemistry of that period was also Brandt's research on zinc, by which he showed that galmeja and blende are ores of zinc, and galitzenstein its vitriol.[1] We have him, besides, to thank for important investigations into the causes of cold- and red-shortness in iron, in the course of which he for the first time makes a proper distinction between these two defects, gives a correct explanation of the cause of red-shortness, and, as far as cold-shortness is concerned, comes very near the truth. Further, Brandt published repeated extensive researches regarding the vegetable and mineral alkalies, in which, among other things, he shows (1756) that common salt contains the same alkali as soda, but saltpetre, on the other hand, a vegetable alkali. Thereby the objections were repelled which various chemists had made to the masterly research of the Frenchman, Duhamel du Monceau, published twenty years before, "Sur le base du sel marin."

Brandt, however, is most renowned in the history of chemistry for his discovery of the metal cobalt. The distinguished German mineralogist Agricola, who died in 1555, speaks of certain minerals which, in consequence of their silver-like appearance, were mistaken for silver ores, but which, when an attempt was made to smelt them, only gave off a poisonous smoke, but yielded no noble metal. They were therefore looked upon by the superstitious miners of that time as silver ores which had been changed by mountain goblins or "kobolds," and were thrown away as valueless, until a German glass manufacturer, Schürer, in the middle of the fifteenth century, discovered that they could be used to give a beautiful blue colour to glass. No thorough examination of the blue colouring matter, however, was made until Brandt, in his "Dissertatio de Semi-metallis," published in 1735, showed that it contained a peculiar metal, which he named cobalt. In the cobalt ores formerly known this metal was combined with arsenic, but in 1742 Brandt examined a cobalt ore from Riddarhyttan, in Westmanland, which was found to be free of arsenic, and afterwards obtained the name Linneit. Nearly fifty years after the publication of Brandt's first paper doubts were cast by foreign chemists on the existence of the new metal on the ground of erroneous experiments.

Next in order to George Brandt among distinguished Swedish chemists comes Henrik Theophilus Scheffer, assayer of the mint at Stockholm, born 1710, died 1759. His most famous work is a research on "The White Gold, or Seventh Metal, called in Spain Platina del Pinto" (*Trans.* of the Swedish Academy of Sciences, 1752), in which Scheffer shows by a complete series of experiments that this "wild American variety of silver" forms a new noble metal. Two years before the same substance, which had long been known to the Spaniards, was referred to as a semi-metal, yet without any further clearing up of its chemical properties. In consequence of the many mystic conceptions, not yet completely rooted out, which, from the time of the alchemists, were connected with the idea "noble metal, the ascertaining of the chemical nature of the "white gold" contributed more than could have otherwise been expected to extend and confirm the sound and truly scientific direction which in a couple of decades became predominant in chemical research in our country. We have besides Scheffer to thank for important improvements in the art of assaying gold and silver, and for an excellent series of lectures in chemistry, published by Thorbern Bergman from notes taken by Alströmer, for the first time in 1775, sixteen years after Scheffer's death, and since several times reprinted both in the Swedish and in foreign languages.

A year before the publication of Scheffer's first paper on platinum the *Transactions* of the Swedish Academy of Sciences contained another important research, "Experiments made with a Species of Ore from Loos Cobalt Mines," by Axel Frederic Cronstedt. These mines had a century before been taken in hand by Kalmeter, and the ore at first yielded a good zaffre. But it soon appeared that part of the ore was impure. It was examined by Cronstedt, and found to contain not cobalt, but a new metal. This new metal Cronstedt afterwards found in various other minerals, among others in a German mineral, Kopparnickel, a copper ore changed by a wicked mountain goblin, "Niccol." The new metal, which has now many practical applications, was called nickel, and was immediately, in accordance with the requirements of science, carefully examined, and the tests for it ascertained by Cronstedt. To show what difficulties attended such investigations at that period it may be pointed out that Buffon in 1777 considered platinum an alloy of gold and iron, and that Sage, renowned in France as an analytical chemist, in 1772, and De Lisle even in 1783, considered koppar-nickel a cupriferous ore. Even in 1801 Haüy did not consider it fully established that nickel was a distinct metal. Further, it ought to be mentioned in connection with Cronstedt's chemical activity that he was the first to draw attention to a mineral, "Bastnäs tungsten," from Bastnäs mines in Westmanland, in which Berzelius, Hisinger, and Klaproth in 1803 discovered cerium, and Mosander in 1839 and 1843 lanthanum and didymium. Cronstedt's special greatness, however, did not lie in the field of chemical but of mineralogical research. Here he prepared the way for the new era.

It was natural that a certain practical skill in distinguishing minerals and ores should speedily be developed in a country so rich in mines as Sweden. We scarcely find a trace of it, however, in the older Swedish literature, for the Mineralogy of Aron Forsius is full to overflowing of the sayings of Arabian authors, but contains only notes on nature studies within the land itself. On the other hand Urban Hjärne's work, "A Short Introduction to Research into Various Kinds of Ores and Rocks, Minerals, &c." (Stockholm, 1694), fortunately written not for the learned but for searchers for ore, unfolds practical views of the subject, and he has in reality connected his name with several new observations in science. Not till after 720, however, did there commence among us in this field a new period. As early as 1730 Bromell published a little, modest but serviceable Mineralogy, which enables us easily to understand the standpoint of the science at that date. Afterwards Linnæus included the mineral kingdom along with the others in his "Systema Naturæ" (first edition, 1735), and attempted to apply in that branch of knowledge the method of going to work which he had used with such success in describing and arranging the products of the animal and vegetable kingdoms. In this way at a later date he gave the exciting touch to De Lisle's work, which created an era in this field. The method of Linnæus was followed by Gottskalk Wallerius, who published in 1747 the first real Handbook of Mineralogy, a work incomparably better than anything that had been written on this branch of knowledge since the time of Agricola. For not only in it was collected all that was previously known in science, but the work was rich in new discoveries. Yet Wallerius still places among the true species of minerals, petrifactions and stone-like concretions from the animal and vegetable kingdoms, pearls, hair-balls, &c.

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[1] It is distinctive of the then standpoint of the science, and of the importance which discoveries that now appear of little moment had for its development, that even so late as 1725 the experienced Saxon mineralogist, Henckel, had no suspicion that blende, which is of common occurrence in the Saxon mines, contains zinc.

It was reserved for Cronstedt to sweep these matters out of mineralogy, and thus draw a correct boundary line between the products of the mineral and animal kingdoms, and to lay the foundation of geognosy by making a proper distinction between minerals and rocks. The work in which these new discoveries were brought together was published, without the author's name, at Stockholm in 1758, under the title, "An Essay on Mineralogy; or, an Exposition of the Mineral Kingdom," afterwards reprinted in a new edition and translated into Danish, English, and German (two editions). In order to give an idea of the revolution in science which Cronstedt carried through, not without violent opposition, I take the following extract from the polemic introduction to his work:—

"Sand is in itself nothing else than small stones, and therefore, if we give sand a place by itself we ought to do the same to pebbles, to earthfast stones, and lastly to rocks. This is just a *multiplicatio entium præter necessitatem.*

"Stones of beasts and fishes are composed partly of phlogiston, salts, and a small proportion of earth, partly of the same matter as the bones of animals, and there is therefore no more reason for including them in a mineral system than the stones of fruits. Soot, tartar, yeast, and such like are too nearly related to the vegetable kingdom. . . . Hair-balls and hat-stuff are so far different that the former is felted together in the entrails of animals *per motum peristalticum*, and the latter by the industry of human hands. May we suppose, then, that hair-balls and animal-stones cannot be included among *relicta animalia?* . . . Meanwhile I flatter myself that those who will follow the introduction here given will not be put to so much trouble with the matters belonging to the mineral kingdom as has happened to myself and others from previously published systems, and that I thus will get some defender against those who are so infected with figuromania and taste for outside work that they are offended at the presumption of passing off marble as limestone, and of placing porphyry among rocks."

This introduction is distinctive of the reform which Cronstedt carried through in mineralogy, and it is distinctive of the standpoint of science before Cronstedt's time that the alteration, so necessary and self-evident as it now appears to be, at first aroused controversy and opposition. To this it conduced in its degree that Cronstedt in general fixed less attention on the outward appearance of minerals than on their chemical properties, to ascertain which he employed the blowpipe with great skill and success. Numerous were the new discoveries with which in this way he enriched the science, and during a quarter of a century his "Essay on Mineralogy" was an unsurpassed *chef-d'œuvre*.

Two years after Cronstedt's death Wallerius retired from his professorship of chemistry in the University of Upsala, and after a lively contest the post was assigned to Thorbern Bergman (born 1735, died 1784), then mathematical assistant. He had not previously made himself known by any *chemical* writings, but from that time he devoted himself with such industry and success to chemical research that within a short time he won for himself a European reputation and the name of being the first chemist of his time. His researches embraced nearly all branches of the chemical science of the period; everywhere he dragged new facts into light or corrected older erroneous statements. Space permits me here only to point to his development of the new chemical analysis in the wet way, and the researches he carried out by the new methods on the most dissimilar substances, for instance on different kinds of iron, by which the composition of pig iron, malleable iron, and steel was first ascertained, on precious stones and siliceous minerals, on a number of salts, &c.; to his comprehensive research on carbonic acid (called by him atmospheric acid), whereby the discoveries of Black, Macbride, and Cavendish relating to this exceedingly important substance were considerably extended and the foundation of the chemistry of carbonic acid laid; to his analyses of mineral waters, in which even their gaseous constituents were estimated; to his examination of the salts of bismuth, zinc, lead, nickel, gold, platinum, and magnesia; to his services to organic chemistry; and finally to his laborious investigation of the laws of chemical attraction, which are still recognised in the science, though in a form much altered, by the labours of Berthollet and others. Bergman also did great service to mineralogy by his comprehensive analytical researches and by his "Sciagraphia Regni Mineralis," the best systematic work on mineralogy since the time of Cronstedt.[1]

Finally, we may further state that Wallerius and Bergman were the founders of agricultural chemistry, the former by his disputation, "Agriculturæ fundamenta Chemica," published in 1761, in Latin and Swedish; the latter through a work, "De Terris Geoponicis," which was communicated to the Academy at Montpellier, and for which he received a prize in 1773. An incalculable service has also been conferred by the Swedish chemists on the development of scientific agriculture by their pointing out the common occurrence of phosphorus in nature, in the mineral kingdom by Gahn in 1780, in the bones of animals by Gahn or Scheele before 1771.

Carl Wilhelm Scheele lived and worked at the same time as Bergman. He did not possess the many-sided learning and deep theoretical insight of the Upsala professor, but, instead, an unsurpassed power of scientific divination, which enabled him, the young apothecary, to mark nearly every year of his short period of activity by "original contributions to chemical science, which, by the influence they exerted on industry, metallurgy, and agriculture, contributed more powerfully than diplomatic negotiations or pitched battles to the development of the last hundred years, and secured him, the modest apothecary of Köping, a place in the first rank of the men of science of all ages and of all countries."

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[1] Bergman's works were for the most part published in the first place as academic disputations or in the *Transactions* of the Swedish Academy of Sciences, but they were afterwards collected in "Opuscula Physica et Chemica," 6 vols., Upsala, 1779. There are numerous translations into foreign languages.

[2] Phosphoric acid, as is well known, forms a constituent in most manures. It was first discovered by the Hamburger Brand (not to be mistaken for George Brandt) in 1669, and, when he kept his discovery secret, a second time by Kunkel (German chemist, for the last twenty-five years of his life mining counsellor in Stockholm, and ennobled by Charles XI. under the name of Löwenstern). That the generally-occurring mineral *apatite* contains phosphoric acid was discovered by Klaproth and Proust in 1788. That bone, horn, &c., may be used as manures was known to Bergman (see *Opuscula*, v. page 106).

In a succeeding paper I propose to give a sketch of the work of Scheele, and to return at the same time to the chemical labours of Bergman.

(*To be continued.*)

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## THE TEMPERATURE OF SPACE AND ITS BEARING ON TERRESTRIAL PHYSICS

FEW questions bearing directly on terrestrial physics have been so much overlooked as that of the temperature of stellar space, that is to say, the temperature which a thermometer would indicate if placed at the outer limits of our atmosphere and exposed to no other influence than that of radiation from the stars. Were we asked what was probably the mid-winter temperature of our island 11,700 years ago, when the winter solstice was in aphelion? we could not tell unless we knew the temperature of space. Again, without a knowledge of the temperature of space, it could not be ascertained how much the temperature of the North Atlantic and the air over it were affected by the Gulf Stream. We can determine the quantity of heat conveyed into the Atlantic by the stream, and compare it with the amount received by that area directly from the sun, but this alone does not enable us to say how much the temperature is raised by the heat conveyed. We know that the basin of the North Atlantic receives from the Gulf Stream a quantity of heat equal to about one-fourth that received from the sun, but unless we know the temperature of space we cannot say how much this one-fourth raises the temperature of the Atlantic. Suppose 56° to be the temperature of that ocean: this is 517° of absolute temperatures which is derived from three sources, viz.: (1) direct heat from the sun, (2) heat from the Gulf Stream, and (3) heat from the stars. Now unless we know what proportion the heat of the stars bears to that of the sun we have no means of knowing how much of the 517° is due to the stars and how much to the sun or to the Gulf Stream.

M. Pouillet and Sir John Herschel are the only physicists who appear to have devoted attention to the problem. The former came to the conclusion that space has a temperature of – 142° C. or – 224° F., and the latter, following a different method of inquiry, arrived at nearly the same result, viz., that its temperatures is about – 239° F.

Can space, however, really have so high a temperature as – 239°? Absolute zero is – 461°. Space in this case would have an absolute temperature of 222°, and consequently our globe would be nearly as much indebted to the stars as to the sun for its heat. If so space must be enormously more transparent to heat rays than to light rays. If the heat of the stars be as feeble as their light, space cannot be much above absolute zero, and this is the opinion expressed to me a few weeks ago by one of the most eminent physicists of the day. Prof. Langley is also of this opinion, for he concludes that the amount of heat received from the sun is to that derived from space as much as four to one; and consequently if our luminary were extinguished the temperature of our earth would fall to about – 360° F.

It must be borne in mind that Pouillet's Memoir was written more than forty years ago, when the data available for the elucidating the subject were far more imperfect than now, especially as regards the influence of the atmosphere on radiant heat. For example, Pouillet comes to the conclusion that, owing to the fact of our atmosphere being less diathermanous to radiation from the earth than to radiation from the sun and the stars, were the sun extinguished the radiation of the stars would still maintain the surface of our globe at – 89° C., or about 53° C. above that of space. The experiments of Tyndall, however, show that the absorbing power of the atmosphere for heat-rays is due almost exclusively to the small quantity of aqueous vapour which it contains. It is evident, therefore, that but for the sun there would probably be no aqueous vapour, and consequently nothing to protect the earth from losing its heat by radiation. Deprived of solar heat, the surface of the ground would sink to about as low a temperature as that of stellar space, whatever that temperature may actually be.

But before we are able to answer the foregoing questions, and tell, for example, how much a given increase or decrease in the *quantity* of sun's heat will raise or lower the *temperature*, there is another physical point to be determined, on which a considerable amount of uncertainty still exists. We must know in what way the temperature varies with the amount of heat received. In computing, say, the rise of temperature resulting from a great increase in the quantity of heat received, should we assume with Newton that it is proportional to the increase in the quantity of heat received, or should we adopt Dulong's and Petit's formula?

In estimating the extent to which the temperature of the air would be affected by a change in the sun's distance, I have hitherto adopted the former mode. This probably makes the change of temperature too great, while Dulong's and Petit's formula adopted by Mr. Hill (NATURE, vol. xx. p. 626), on the other hand, makes it too small. Dulong's and Petit's formula is an empirical one, which has been found to agree pretty closely with observation within ordinary limits, but we have no reason to assume that it will hold equally correct when applied to that of space, any more than we have to infer that it will do so in reference to temperature as high as that of the sun. When applied to determine the temperature of the sun from his rate of radiation, it completely breaks down, for it is found to give only a temperature of 2130° F. (*Amer. Jour. Science*, July, 1870), or not much above that of an ordinary furnace.

But besides all this it is doubtful if it will hold true in the case of gases. From the experiments of Prof. Balfour Stewart (*Trans.* Edin. Roy. Soc., xxii.) on the radiation of glass plates of various thicknesses, it would seem to follow that the radiation of a material particle is probably proportionate to its absolute temperature, or, in other words, that it obeys Newton's law. Prof. Balfour Stewart found that the radiation of a thick plate of glass increases more rapidly than that of a thin plate as the temperature rises, and that, if we go on continually diminishing the thickness of the plate whose radiation at different temperatures we are ascertaining, we find that, as it grows thinner and thinner, the rate at which it radiates its heat as its temperature rises becomes less and less. In other words, as the plate grows thinner its rate of radiation becomes more and more proportionate to its absolute temperature. And we can hardly resist the conviction that if it were possible to go on diminishing the thickness of the plate till we reached a film so thin as to embrace but only one particle in its thickness, its rate of radiation would be proportionate to its temperature, or, in other words, it would obey Newton's law. Prof. Balfour Stewart's explanation is this: As all substances are more diathermanous for heat of high than low temperatures, when a body is at a low temperature only the exterior particles supply the radiation, the heat from the interior particles being all stopped by the exterior ones, while at a high temperature part of the heat from the interior is allowed to pass, thereby swelling the total radiation. But as the plate becomes thinner and thinner, the obstructions to interior radiation become less and less, and as these obstructions are greater for radiation at low than high temperatures, it necessarily follows that, by reducing the thickness of the plate, we assist radiation at low more than at high temperatures.